INVESTIGATIONS ON LIGHT AND HEAT, made and published wholly or in part with appropriation from the RUMFORD FUND.

X.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XII. — PHOTOMETRIC RESEARCHES.

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Presented Feb. 11, 1880.

ALTHOUGH many forms of Photometer have been devised within the last hundred years, little has been done towards measuring the brilliancy of our brighter lights, and nothing, so far as I am aware, towards determining the relative intensity of their component colors. With these two objects, and especially the latter one, in view, the following determinations have been made.

The first difficulty encountered was to obtain a steady light, of which the ratio of the component colors should be constant, for use as a standard. Experiments were made using a platinum crucible containing a salt having a high point of fusion. This was to be kept just at the melting point, and thus a constant temperature would be obtained, and consequently a constant light. Several difficulties were encountered, however; among others the cracking of the crucible, owing to the alternate melting and solidification. And moreover the light was not sufficiently brilliant to be wholly satisfactory, so that the idea had to be given up. One interesting result, however, was obtained. Theoretically, the same amount of light would be given out in any direction by a curved surface, as by a flat one; but it was found that at the very edges, the curved surface was noticeably more brilliant than in the middle. That this effect was not due to contrast was shown by placing a brilliant background behind the crucible, when, if contrast produced the effect, it would now have been reversed. But no change in the result was noticeable. Should this result be confirmed, it has an interesting application. The opacity of the atmosphere surrounding the sun has been calculated on the supposition that the theoretical rule is correct; hence, if

incorrect, it is clear that the value so obtained must be somewhat increased.

Several of the artificial lights were next tried. The first one to suggest itself was naturally the standard candle; but a very few experiments sufficed to show that it would not do; and I have since found that of all the lights examined, including the Sun, Lime, Magnesium, and Electric, none was so uncertain in color as the standard candle. After experimenting with several other lights, the standard finally adopted was the gas flame from an Argand burner, using about 5 cu. ft. per hour. A diaphragm .568 cm. in diameter, and having an area of .253 $cm.^2$ was placed over the most brilliant portion of the flame. A standard was thus obtained which would be almost absolutely constant, in both light and color, during any one set of experiments (usually occupying about an hour), and which I judge from subsequent experiments would vary very little even in the course of a month. The candle-power of the whole flame when burning 5 $ft.^3$ per hour is about 16.0, that of my standard, .67.

Having obtained a satisfactory light, the next step was to get an instrument by means of which the various lights to be measured could conveniently be compared. For this purpose I use an ordinary double-slit spectroscope, furnished with a grating, having the lines (6480 to the inch) photographed on glass. In front of the slits are placed two right-angled prisms, arranged to reflect the light from opposite directions into the collimator. On looking through the instrument, the two spectra will be seen one above the other, and by means of two sliding metal plates, placed at the focus of the telescope, the spectra may be cut down so that only a narrow vertical strip of each shall be visible.

The standard light is fastened upon a little car, rolling upon a track over a fixed scale, by means of which its distance from the slit is measured. The light to be compared is placed at a known distance on the other side of the slit; the telescope is pointed to some particular color and the standard moved backwards or forwards till the two spectra are of the same brilliancy. The distance is then read off on the scale. In measuring the red and violet ends, it was usually found necessary to place the light to be measured nearer to the slit than for the other colors. The "standard" slit was kept at a constant breadth of .056 mm. through all the experiments, and the light could be moved from it through a distance of from 10 to 60 cms. I found, however, that it was generally better not to place the standard nearer than 15 cms. It will be noticed that the slits are generally kept

quite narrow, as greater accuracy can be attained when the colors are rather faint. Four points in the spectrum were selected for observation, and from these the intervening portions were interpolated. These points were equidistant, and were situated one in the red, one in the yellow, one in the green, and one in the violet; or to speak more accurately, in the neighborhood of the lines C, D, and b', and at a point between F and G. They will be designated hereafter by the letters R, Y, G, and V.

I give below my observations on the lime light in full, as a fair example of the accuracy of the instrument, and of the method employed. It will be seen that the first two figures only are of value, the third being used merely for obtaining the mean result. In all my experiments I divide my observations into two sets, made at different times, and the light extinguished between whiles; each set is divided into four series, one for each color, and each series consists of at least three, and frequently more observations; thus making at least twenty-four observations on each light. The means of the series are then taken and compared two and two, and their means obtained. From these last the relative brilliancies as compared with the standard are calculated, and plotted as a curve. (See Fig. 1.)

Lime Light.

Breadth of Slit, .011 mm.

1st Set.

Distance to Slit, 1.5 m.		Distance to Slit, 3.0 m.	
R	Y	G	V
21.2	38.8	39.2	21.3
26.9	39.4	36.4	25.7
25.9	35.0	34.2	23.4
3) 74.0	3) 113.2	3) 109.8	3) 70.4
1.5) 24.7	3) 37.7	3) 36.6	3) 23.5
16.4	12.6	12.2	7.8

2d Set.

Distance to Slit, 1.5 m.		Distance to Slit, 3.0 m.	
R	Y	G	V
28.1	42.1	36.5	21.2
21.3	33.2	38.2	25.9
30.2	41.1	36.2	17.6
22.9	45.9	. . .	26.9
29.6	. . .	. . .	. . .
25.3	. . .	. . .	. . .
6) 157.4	4) 162.3	3) 110.9	4) 91.6
1.5) 26.2	3) 40.6	3) 37.0	3) 22.9
17.4	13.5	12.3	7.6

Mean Scale Readings of both Sets.

R	Y	G	V
16.4	12.6	12.2	7.8
17.4	13.5	12.3	7.6
16.9	13.0	12.2	7.7

Relative Brilliancies.

R	16.9^2	=	28561	Recip.	=	3501	∝	59
Y	13.0^2	=	16900	"	=	5917	"	100
G	12.2^2	=	14884	"	=	6718	"	113
V	7.7^2	=	5929	"	=	16866	"	285

After measuring the brightness, I observed the limits of the spectrum under two different brilliancies, and the very curious effect was noticed, that while the red end under the increased illumination advanced considerably, — in the present instance 27′, — the violet did not move at all. The same effect is noticeable in all the lights to a greater or less extent, the violet usually moving from 1′ to 3′. This is probably accounted for by the fact that the fluids of the eye absorb nearly all the rays of short-wave length, thus cutting off all the spectra at nearly the same place. The position of the red end, on the other hand, depends merely on the intensity of the light.

Limits of the Spectrum.

Distance 1.5 m. R	Slit .2 mm. V	Distance 1.0 m. R	Slit .4 mm. V
41° 55′	37° 23′	42° 24′	37° 24′
56	23	24	24
54	24	18	21
41° 55′	37° 23′	42° 22′	37° 23′

These figures do not represent the deviation of the ray, but merely the numbering on my divided circle. Reducing them to wave lengths we obtain: —

R	V	Slit.	Distance.
709	414	.2 mm.	1.5 m.
740	414	.4 mm.	1.0 m.
31	0	Advanced.	

Next the total brilliancy of the light in candle-powers is measured. In the present case, two determinations were made, one at the end of each set. These measurements were made with a Bunsen pho-

tometer. As the arrangement of the scale in this instance was somewhat complicated, and the form of the observations is well known, I will merely state the results in the two instances as 90 and 84 candle-power. I have since measured the light, and obtained a maximum brilliancy of 231 c. p. And from this, by varying the supply of gas, and the distance of the lime from the burner, the light could be diminished gradually to any extent.

The intrinsic brilliancy is then obtained by placing a diaphragm of known size over the light and remeasuring. As no good standard of intrinsic brilliancy exists, I adopt for the present purpose the light given off by my "standard." This is about .67 of a candle-power at the same distance. When at a maximum, the intrinsic brilliancy of the lime was 121 st. when the total light was 90 c. p. The intrinsic was 54 st.

Probable Error.

Using a perfectly invariable light, the mean probable error of six observations for the different colors was found to be: — red, 6.7 per cent; yellow, 3.4; green, 2.4; violet, 6.1. These figures may seem rather large, but when we consider that in most of the lights the chief discrepancies are caused not by instrumental errors, but by differences of color, and brilliancy in the lights themselves, we see that it would not be much advantage to have the instrument more accurate than it is; and that if we are to measure the lights at all, we must allow some pretty large variations. Moreover the different lights vary from each other frequently by more than 100 per cent, which leaves room for quite large differences. In fact, we find this to be a subject where the magnitudes are of great range; and accuracy such as we are in the habit of obtaining in other branches is out of the question. The mean probable error of six observations with the Bunsen photometer, on a constant source, varies from .5 per cent under the most favorable circumstances, up to 2 or 3 per cent when less favorable.

Description of Plate I.

On this plate each broken line represents some particular light. The abscissae denote wave lengths expressed in .00001 of a mm. The ordinates represent the brilliancies of each color, the unit being the brightness of the "standard" for that particular wave length. The standard light is therefore represented by the horizontal line St. As observations were taken only at four particular points, we have no means of knowing the shape of the curves outside of these;

they are therefore prolonged, as horizontal dotted lines, to the farthest limit at which their spectra could be clearly traced. Each curve is designated by a letter, viz.: — St., standard; G, gas; C, candle; L, lime; Mo, moon; E, electric; Mg, magnesium; Su, sun. The positions of the chief solar lines are also marked for convenience of reference. It will be noticed as a curious fact, that the lines *a*, C, D, E, a point between F and G and the line H, are almost exactly equidistant; the greatest difference being in the case of C, — .9 mm. on the present scale. B is just midway between *a* and C, G midway between the missing line and H.

The following lights were measured in the same manner as the lime light. I shall therefore give only a synopsis of my observations on them.

Gas Light.

This is probably the easiest of all the lights to measure, on account of the steadiness and uniformity of its flame. An Argand burner was employed, burning about 5 ft.^{3} per hour. It will be seen that it is considerably bluer than the standard, containing 25 per cent more violet. This probably comes from the bluer portions of the flame, which are generally supposed not to give off much light. It has been the custom in constructing gas-burners to suppress these portions as much as possible, but it may be that what a flame thus gains in brilliancy it loses in whiteness.

The following mean readings were obtained: —

R	Y	G	V
14.5	13.1	12.4	9.4
14.0	11.3	11.6	12.4
14.2	12.2	12.0	10.9

Brilliancies.

74	100	103	125

Limits.

R	V	Slit.	Distance.
690	424	.05 mm.	1.4 m.
726	426	.40 mm.	1.0 m.
36	—2	Advanced.	

Total brilliancy, 16 c. p. Intrinsic, 1 st.

"Intrinsic" refers in all cases to the brightest part of the flame.

Standard Candle.

This was found one of the hardest lights to manage. It was necessary to snuff the wick continually, otherwise the flame would become too brilliant, besides which too much red would be introduced. After a little practice, however, better results were obtained, and when calculated, the curve followed very closely that of the gas-flame. (See Fig. 1.)

Mean Readings.

R	Y	G	V
20.5	17.9	16.5	19.2
22.5	19.0	19.6	12.6
21.5	18.4	18.0	15.9

Brilliancies.

73	100	104	134

Limits.

R	V	Slit.	Distance.
677	432	.2 mm.	1.0 m.
691	429	.4 mm.	.7 m.
14	3	Advanced.	

Total brilliancy, 1 c. p. Intrinsic, 1 st.

Lime Light.

This was the next flame measured, and has already been referred to. It is very steady and uniform, and comparatively easy to measure.

Magnesium Light.

This was obtained by burning two coils of wire simultaneously in a lamp adapted for that purpose. The coils weighed together 56 gms., and burned at the rate of .37 gms. per minute, and would therefore last without renewal for about two hours and a half. Three bright lines were visible in the spectrum, namely D, b', and a line which would come about half way between b' and F. These lines fortunately did not come into the field of view in either of my measurements, but would be represented on the curves in Fig. 1. by long vertical lines drawn at these points. The light itself had a very curious appearance when viewed through colored glass. It was the shape of a broad, inverted candle-flame, wavering from side to side, and sometimes splitting in two for nearly its whole length. There seemed to

be no real flame, but a brilliant, striated structure, from which poured up clouds of smoke. The flickering did not annoy me as much as I had expected in my measurements, but was most noticeable in the red. The limits, however, varied considerably, so I took their maximum position.

Mean Scale Readings.

R	Y	G	V
473	310	229	100
295	362	222	100
384	336	225	100

The second red was clearly wrong; it was therefore discarded and the first only used.

Brilliancies.

R	Y	G	V
50	100	223	1,129

The well-known blueness of the flame is clearly accounted for by the great quantity of violet rays present.

Limits.

R	V	Slit.	Distance.
695	411	.03 mm.	1.0 m.
715	408	.04 mm.	1.0 m.
20	3	Advanced.	

Total brilliancy, 215 c. p. Intrinsic, 20.8 st.

ELECTRIC LIGHT.

The light was obtained with a Foucault regulator, using 40 pint Grove cells. Six observations were made in each series, instead of three, as in the case of the other lights. The intrinsic brilliancy of both the arc and the carbons was measured. I found the arc to be much fainter, and to vary considerably, while the carbons remained quite constant. If a more powerful current had been used, I think the intrinsic brilliancy of the arc might have increased a little, but the chief difference would have been in its area and that of the ignited carbons.

Mean Scale Readings.

R	Y	G	V
192	178	151	68
238	144	155	57
215	161	153	62

The second yellow was here discarded as obviously incorrect.

Brilliancies.

R	Y	G	V
61	100	121	735

Limits.

R	V	Slit.	Distance.
697	411	.100 mm.	1.5 m.
735	411	.197 mm.	1.0 m.
38	0	Advanced.	

Total brilliancy, 362 c. p. Intrinsic, carbons, 3141.
Arc, 645.

Moonlight.

On account of interruption by clouds, the observations are not quite so satisfactory as some of the preceding ones. Only one series was made on the violet. The moon was just ten days old, and the observations lasted from 9 to 10 P. M. Altitude, 44°.

Mean Scale Readings.

R	Y	G	V
440	461	326	242
550	588	415	...
...	565	...	...
495	538	370	242

It would seem as if the last two yellows were too faint. They were therefore discarded.

Brilliancies.

R	Y	G	V
87	100	155	363

It will be noticed that of all the violet rays sent out by the sun, very few are reflected from the moon (see Fig. 1.), and that the proportion of red rays is quite large, indicating that the surface might partake somewhat of that color, — perhaps like brown lava. And in this case its reddish appearance during total eclipse may not be wholly, as heretofore supposed, due to the absorption of the blue from the solar rays by our atmosphere.

On account of clouds, the limits of the spectrum were not determined.

The total brilliancy was observed several days later, — the day before full moon. Time, 9 P. M., altitude, 20°. Observations were made with both the Bunsen and the Rumford photometers, and are given in full below. Unit, .1 of an inch.

Bunsen.		*Rumford.*
C. Side.	M. Side.	
883	887	1,097
850	892	1,133
882	913	1,110
956	937	1,115
983	906	1,125
911	907	1,116 { Mean distance of candle to screen.
Limits.		
1,002	1,043	1,190
790	822	996
896	927	1,093 { Mean distance of candle to screen.
Difference of Limits.		
212	221	204

Candle-power at 1 Meter's Distance.

Bunsen, .187. Rumford, .124.

The observations with the Bunsen were made from both sides of the disc. In those marked C side, I placed my eye on the side of the candle, in the other it was on the side of the moon. The two means agree very closely; but it was noticed that when the yellow light of the candle passed through the oiled paper, the spot almost completely disappeared; on the other hand, when it was reflected directly from the surface, the setting was much more difficult to make. This difference was very marked, and an examination of the results will show that those made on the side of the moon agree much better than those made on the other side. I shall refer to this point again when I come to the measurements of the sun. On using the Rumford photometer, I was struck with the fact that the measurements did not at all agree with those made by the Bunsen. They agreed with each other, however, more nearly than those made by that instrument, and the difference between their limits was less.

I then set the screen at the mean of the Bunsen readings, but could not convince myself that the shadows were equally dark. The

effect is probably subjective, owing to the great difference of color, and the Bunsen readings are the ones to be relied upon. This would show that the Rumford must never be used to measure lights of different colors, unless the constant error is allowed for. In this case, it amounts to 50 per cent of the whole reading.

Sunlight.

My observations on this source were somewhat interfered with by clouds; although on the days available, it was generally clear in the mornings, it nearly always clouded up in the afternoons, which latter were the only times the observations could be made. The first R, Y, and G, were observed at 1 P.M., altitude of sun, 57°, and the rest between 3 and 4.30 P.M., altitude of sun, about 30°.

Mean Scale Readings.

R	Y	G	V
592	352	276	54
454	325	186	50
. . .	369	201	88
523	349	221	64

Brilliancies.

R	Y	G	V
45	100	250	2971

The enormous value of the violet as compared with that of the preceding lights is very striking. (See Fig. 1.)

Limits.

The spectroscope was exposed to the full rays of the sun. The second V, could not be determined on account of the large amount of diffused light admitted.

R.	V	Slit.
728	395	.030 mm.
742	. . .	.076 mm.
14	. . .	Advanced.

The total brilliancy of the sun, when at an altitude of 25°, I found to be 64,700 c. p. at 1 meter's distance. Another time, when at 40°, I found it 82,000. That is, it would be equal to about 350,000 full moons. To understand this comparison better, we may add that if the whole visible heavens were turned into one extensive full moon, it would give rather less than one quarter of the light of the sun. The brilliancy has previously been stated at 600,000 full moons.

Intrinsic Brilliancy 361,000 *st.*

These measurements were made with the Bunsen photometer, and were all observed from the same side of the disc as the sun. Judging from my measurement of the moon, I had supposed that it would be easier to make my observations from this side, but I was not prepared for the great difference exhibited. From the side of the sun the spot disappeared nearly as perfectly as when measuring a gas flame, particularly if the line of sight was nearly perpendicular to the disc, and the eye was thrown out of focus for it. From the side of the gas, the appearance was that of a bright yellow spot on a bright blue background; and the comparison was almost impossible. The varying brilliancy of different parts of the sun's disc was very marked. I took, as usual, the brightest portion, namely, the centre.

In order to determine the amount of light lost by the porte lumière, a reflecting photometer was planned and constructed. A somewhat lengthy series of observations showed that the light lost with the best plate-glass mirrors, 3 mms. in thickness, varied from about 17 to 24 per cent; depending on the angle made by the incident and reflected rays. I believe no wholly satisfactory results have yet been attained, and the measurement has been attempted only once or twice. My results are represented in Fig. 3. The abscissae represent the angle of the incident and reflected rays. The left-hand ordinates give the per cent of light reflected, the right-hand ones the per cent lost.

On the Measurement of High Temperatures by the Spectroscope and Photometer.

It is a fact of common experience, that as we heat a body to higher and higher temperatures, it becomes brighter and at the same time whiter, — in other words, more violet light is given off. Here, then, we have a means of determining qualitatively the temperature of any source. Now if we only knew by what law, either the intrinsic brilliancy, or the violet rays increased with the temperature, and knew at the same time the melting points of some of the metals, we should be able to form some idea of the temperatures, not only of the lime, electric, and magnesium lights, but also of the sun and fixed stars.

Three attempts have been made to determine the temperature of the sun; one by Secchi, supposing the temperature proportional to the radiation of heat; the second founded on Newton's law of cooling; the third dependent upon a numerical exponent, determined from

the experiments of Dulong and Petit. The first two give a temperature of several million degrees, the third about two thousand. I give below the opinions of four well-known modern astronomers, three of them having made the sun their specialty.

Père Secchi says, "As to the absolute value of this temperature, we cannot fix it with certainty. . . . . Nevertheless, this temperature must be several million degrees of our thermometer, and capable of maintaining all known substances in a state of vapor."

Prof. Newcomb's views: "For the temperature of the photosphere it seems likely that the lower estimates are more nearly right, but the temperature of the interior must be immensely higher."

Prof. Young's views: "As to the temperature of the sun's surface, I have no settled opinion, except that I think it must be much higher than that of the carbon points of the electric light. . . . . The estimates dependent on Newton's law seem to me manifestly wrong and exaggerated; on the other hand, the low estimates of the French physicists seem to me hardly more trustworthy."

Prof. Langley says, "The temperature of the sun is, in my view, necessarily much greater than that assigned by the numerous physicists, who maintain it to be comparable with that obtainable in the laboratory furnace; but we cannot assign any upper limit to it, until physics has advanced beyond its present merely empirical rules connecting emission and temperature."

Now we know from the experiments of Prof. Draper and others, that as the temperature rises, the light increases *much* more rapidly than the heat; and let us suppose that this law holds good up to the temperature of the sun. Since we do not know any terrestrial high temperature with certainty, great accuracy is manifestly out of the question. Heated bodies begin to give out light at about 500° C; silver melts at about 1,000° C. Many determinations of the melting point of platinum have been made, which give it in the neighborhood of 2,000° C. The temperature of the electric arc has been estimated at between 3,000° and 4,000° C, — let us say, 3,500°. The intrinsic brilliancy of the carbons of the electric light we found to be 3,141, that of the sun, 36,100. This was determined at an altitude of 25°, — let us suppose our atmosphere removed and double it, obtaining 72,000. It has been shown by my brother, Prof. Pickering, that only about one fourth the light from the centre of the sun's disc reached the earth. We will therefore multiply its brilliancy by 4, obtaining 288,000. Divide by the intrinsic brilliancy of the electric light (3,141), and we find the sun to be 90 times as brilliant. Then

the heat can certainly not be more than 90 times as great, and is probably much less. Since bodies begin to glow at about 500° C, the following equation will determine the solar temperature: —

$$90\ (3{,}500 - 500) + 500 = 270{,}500°\ \mathrm{C}.$$

Our upper limit would thus be brought down from several millions of degrees to about 270,000° C.

Now as to the lower limit. The temperature of the hottest blast furnaces is about 2,000° C, or about that of the lime light. That the sun is far hotter than this, or even the electric light, is manifest by an examination of the curves in Fig. 1. Let us take 8,000° as a lower limit, as found by inspection. On observing the spectrum of melted silver, I found that it just about reached to the violet rays. Also the heat of the oxyhydrogen jet is approximately the melting point of platinum. Let us now construct a curve, Fig. 2., in which the unit of abscissas shall be 1,000° C, and the ordinates the same as in Fig. 1., but on a different scale. Then the point Si will represent the position of melted silver, L the lime-light or melted platinum, and E the electric light. We find that these three points all lie in a straight line. Then if the temperatures we adopted were correct, this would give us a very simple empirical law, viz: — *The temperature is always proportional to some function of the ratio of any two assumed wave-lengths. For artificial sources, for the wave-lengths* 585 *and* 455, *it varies directly as this ratio.* Supposing this law to be uniformly true, the temperature of the sun would be 11,000° C. But from a comparison of the experiments of Dr. Vogel, and Prof. Pickering, it would seem that the sun's atmosphere absorbs a much larger proportion of the violet rays, than it does of the yellow. We know this to be the case with our atmosphere, therefore let us double the temperature (and this coefficient cannot be very far out of the way), and we may therefore conclude that the temperature of the sun is approximately 22,000° C.

This amount is, we notice, considerably within the limits we had previously set.

Upon this principle, the temperature of the magnesium light, perhaps the highest terrestrial temperature we have yet attained, would be 4,900° C, as shown by Fig. 2. Its small intrinsic brilliancy is readily accounted for, when we recollect that this depends on the area of the ignited solid matter, and that this, in the case of the magnesium light, consists almost wholly of the impalpable oxide which forms the smoke.

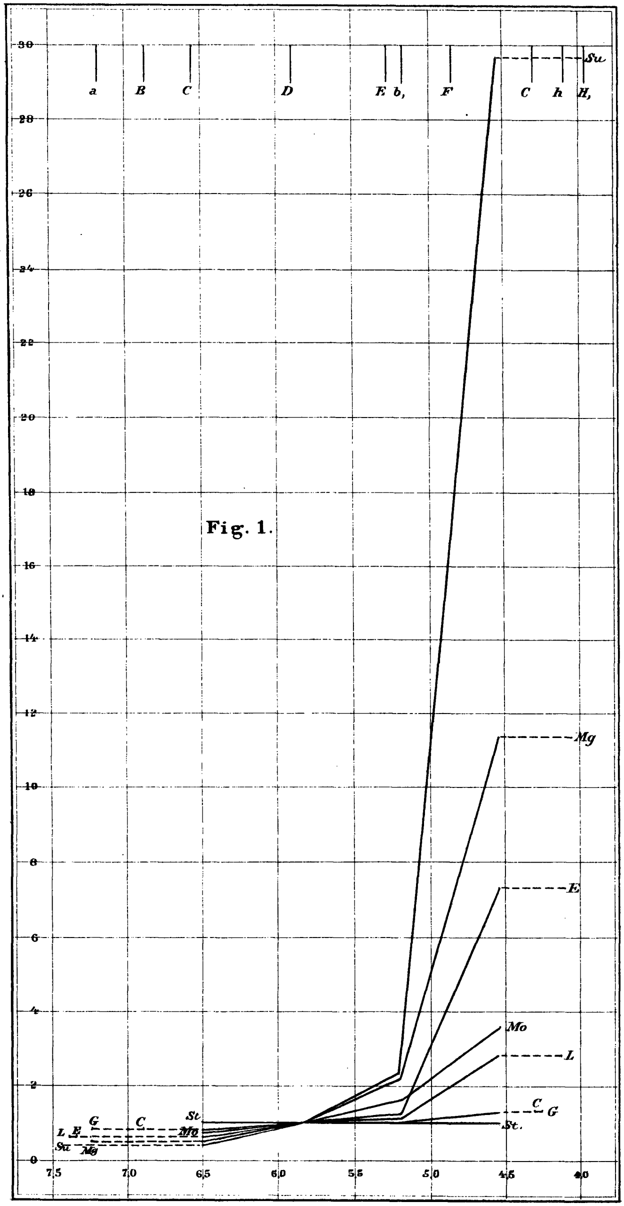
It is perhaps unnecessary to add, that the above-mentioned law of the increase of the violet rays is inapplicable to flames like the blue part of the gas, where no solid matter is introduced. It probably applies in a modified form, to lime flames, as witness the disappearance of the blue line in the strontium spectrum, at low temperatures.

Second Estimation of the Sun's Temperature.

Below is given a table showing the total and intrinsic brilliancies, as well as the temperatures, of the several sources referred to in this article.

Source of Light.	Total Brilliancy.	Intrinsic Brilliancy.	Temperature.	Absolute Tem.	Log. Int. Bril.	Log. Abs. Temp.
Heated Body......	0	0	500	800	$-\infty$	2.93
Melted Silver.....	.....	.....	1,000	.....	....	....
Gas or Candle.....	16...1	1	1,200	1,500	0.00	3.18
Lime light........	231	121	2,000	2,300	2.08	3.36
Electric light......	362	3,141	3,500	3,800	3.50	3.58
Magnesium light..	215	21	4,900	.....	....	....
Sun (observed)....	82,000	36,100	.....	.....	....	....
Sun (corrected)....	.....	288,000	22,000	22,300	5.46	4.34
Lower limit........	.....	.....	.....	7,600	....	3.88
Upper limit........	.....	.....	.....	50,000	....	4.70

Let us now construct a curve with the figures of the seventh column as abscissae and the sixth as ordinates. The gas flame, although not properly speaking an incandescent body, may still be used to fix a lower limit to our curve at that point. This curve is represented in Fig. 4. The horizontal line, Su, represents the corrected intrinsic brilliancy of the sun. It will be seen that the curve cannot intersect it to the left of the left-hand dotted line, and is not likely, so far as one can judge from the form of the curve, to cross it to the right of the right-hand one. These would give to the sun limiting temperatures of 7,600° and 50,000° C. The middle dotted line corresponds to the temperature we previously found of 22,000° C.


a B C D E b, F G h H,
Su
Mg
E
Mo
L
C G
St.
St
G C
L E Mo
Su Mg
30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
7,5 7,0 6,5 6,0 5,5 5,0 4,5 4,0
Fig. 1.

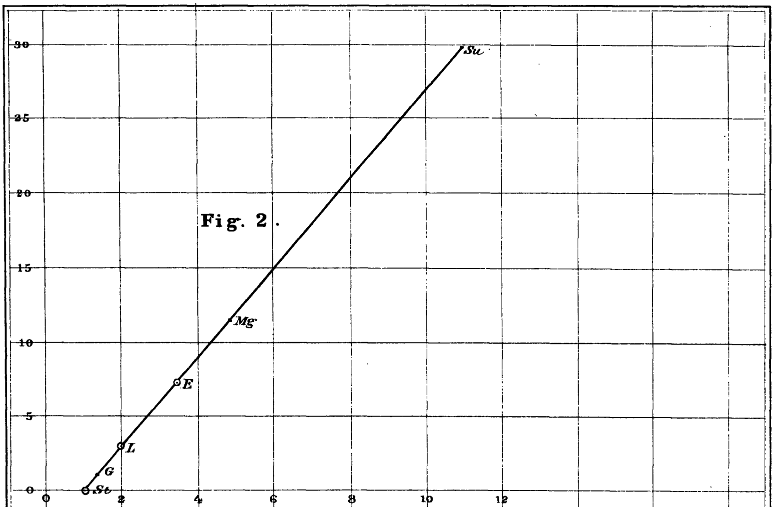


Fig. 2.

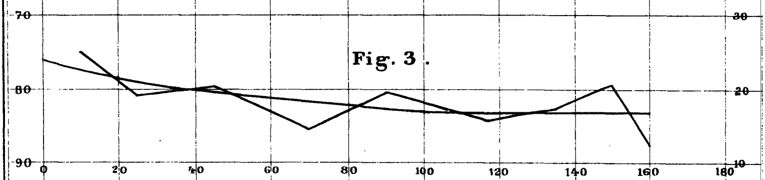


Fig. 3.

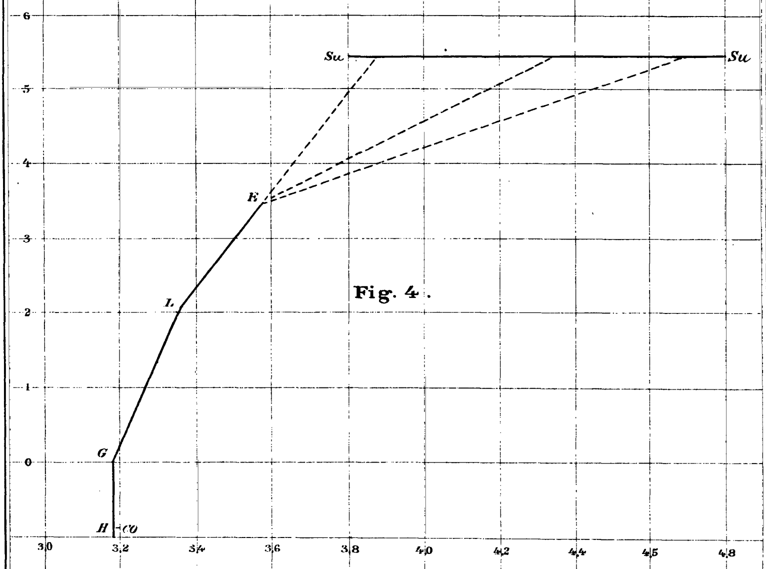


Fig. 4.